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(54) Voltage-controlled oscillator with automatic center frequency calibration

(57) A voltage-controlled oscillator with automatic center frequency calibration. The frequency range (FOUT) of the oscillator is increased because of the presence of a switchable capacitor arrangement (SCA) which add or remove extra capacitors (XC1; XC2) in parallel with the variable capacitor (CV) of the resonant circuit (CV, L). Different voltage versus frequency characteristics (CHL, CHM, CHH) are so obtained. The control of the switchable capacitor arrangement is performed by a control signal provided (SC) by an oscillator control device (OCD).

The control device also sends a reset pulse (RES) to a feedback device (FB) when a control voltage (VCTRL) reaches predetermined low (VTL) or high (VTH) voltage limits of the characteristics. With this reset pulse, the control voltage is reset to an intermediate voltage (VTM) in the middle of the range between the low and the high voltage limits. By resetting the control voltage, the output frequency is also brought to an average value, i.e. is centered.

The voltage-controlled oscillator also preferably comprises a selection device (MX) adapted to immediately change the value of the control voltage to the intermediate voltage. The selection device operates faster than the feedback device.

In a preferred embodiment, memory cells are provided to store control signals corresponding to different output frequencies, i.e. channels of a mobile telecommunication system such as the GSM. The stored control signals are applied to the switchable capacitor arrangement to improve the jump to a steady state of the voltage-controlled oscillator, e.g. starting from power-down.

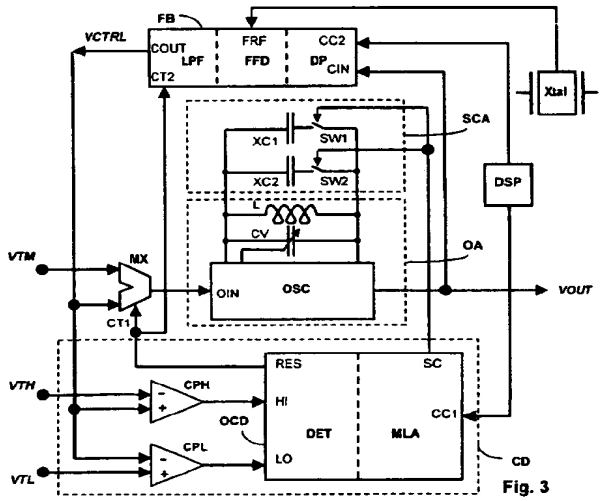

Fig. 3

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Description

[0001] The present invention relates to a voltage-controlled oscillator including an oscillator arrangement with a control input, an output terminal and a variable capacitor, said oscillator arrangement being adapted to provide, at said output terminal, an output signal having a frequency that is a function of the value of said variable capacitor, said value being controlled by a control voltage applied to said control input.

[0002] Such a voltage-controlled oscillator is already known in the art. It generally forms part of a Phase Locked Loop [PLL] arrangement wherein the frequency of the output signal has to be selected within a relatively large frequency range. This is for instance the case when the voltage-controlled oscillator is used in mobile telecommunication systems and if different transmission protocols, such as the known Global System for Mobile communications [GSM] at 900 MHz and Digital Enhanced Cordless Telecommunications [DECT] or Digital Crossconnect System [DCS] in the 1,800 MHz frequency band, have to be covered by a same circuit. Since the frequency is dependent of the control voltage, the latter must then also be able to vary within a relatively large voltage range.

[0003] Furthermore, due to variations in the processing technology, the frequency of the output signal may shift, for a same control or tuning voltage, from the desired one by a large amount. Here again, a solution of using a large tuning range requires a high supply voltage and/or an abrupt variable capacitor or "varicap". A large tuning range results in a large sensitivity of the voltage-controlled oscillator, which severely influences the surrounding parts of the PLL arrangement.

[0004] The trend is now however to reduce the supply voltage in order to reduce accordingly the production cost. Low supply voltage means a reduction of the number of batteries and allows using "deep submicron technology" that permits to reduce the production cost but that can not accept high supply voltages because of risks of break-down.

[0005] A problem rising with the reduction of the supply voltage is that a single voltage-controlled oscillator may then no longer reach the limits of the requested frequency range.

[0006] A possible solution is to design and fabricate several voltage-controlled oscillators with "center" frequencies shifted by a certain amount. A center frequency is the frequency at which the voltage-controlled oscillator should normally operate and that preferably corresponds to a control voltage having an average value, i.e. in the middle of the supply voltage range. Only the voltage-controlled oscillators having the correct frequency, under the actual technology characteristics, should then be selected and activated. However, such a solution is avoided because of the relatively high cost of the components and results in a non-efficient process.

[0007] Another possible solution is to perform a digital calibration of the center frequency with a factory trimming. However, digital factory calibration is costly and does not cover variations over the products lifetime.

[0008] An object of the present invention is to provide a voltage-controlled oscillator of the known type but adapted to operate with a relatively low power supply, while allowing a large operational frequency range and keeping the production cost low.

[0009] According to the invention, this object is achieved due to the fact that said voltage-controlled oscillator further includes a calibration device and a switchable capacitor arrangement, said calibration device comprising a comparator arrangement coupled to an oscillator control device and said switchable capacitor arrangement comprising a plurality of switches coupled to capacitors, that said comparator arrangement has a first input to which said control voltage is applied, at least a second input to which a predetermined reference voltage is applied, and an output connected to a level input of said oscillator control device, that said oscillator control device has a control output coupled to switch control inputs of said switches, said switches being adapted to connect and to disconnect at least one of said capacitors of said switchable capacitor arrangement in parallel to said variable capacitor, and that, in order to control said switches, said oscillator control device is adapted to activate a control signal at said control output if a signal received at said level input indicates that said control voltage has reached said predetermined reference voltage.

[0010] In this way, when the control voltage reaches the predetermined reference voltage, the fact of adding or removing capacitors in parallel with the variable capacitor of the oscillator arrangement makes the frequency to jump towards another control voltage versus frequency characteristic. As a result, in function of the number of capacitors branched in parallel with the variable capacitor of the oscillator arrangement, different frequencies may be obtained for a same control voltage. This allows to increasing the frequency range of a single voltage-controlled oscillator at relatively low cost and is especially useful in low power supply applications.

[0011] Another characterizing embodiment of the present invention is that said voltage-controlled oscillator further includes a feedback device having a feedback input to which said output terminal is connected and a feedback output at which said feedback device is adapted to provide said control voltage, that said feedback device further has a feedback control input to which a reset output of said oscillator control device is connected, said oscillator control device being adapted to apply a reset pulse to said reset output when said control signal is activated, and that said feedback device is adapted to provide, at said feedback output, said control voltage as a function of the frequency of a signal at said feedback input when no reset pulse is received from said oscillator control device, and to provide said control

voltage equal to a predetermined middle reference voltage when a reset pulse is received from said oscillator control device.

[0012] When the control voltage changes, say increases, the frequency of the output signal also increases according to a control voltage versus frequency characteristic of the voltage-controlled oscillator. When the control voltage reaches the predetermined reference voltage, the control signal is activated by the oscillator control device and causes the frequency to jump to another control voltage versus frequency characteristic, i. e. to another frequency value. This new frequency value is then generally higher than the requested frequency. This is for instance the case where the control voltage is used for fine-tuning purposes. As a consequence, the control voltage, being then anyway to high and not allowed to increase anymore, needs to be decreased to obtain the correct frequency value. The oscillator control device applying a reset pulse to the reset output when the control signal is activated performs this. This forces the feedback device to provide a control voltage equal to the predetermined middle reference voltage. This new control voltage is lower than the previous one so that it may again increase thereby increasing the frequency of the output signal.

[0013] Preferably, said predetermined middle reference voltage has an intermediate value between said predetermined low reference voltage and said predetermined high reference voltage.

[0014] The predetermined middle reference voltage is thus generally a voltage in the middle of the supply voltage range. This allows the frequency to be changed in both directions, i.e. up or down, starting from an average value.

[0015] In a variant embodiment, the present invention is characterized in that said voltage-controlled oscillator further includes a selection device having a first selection input to which said control voltage is applied, a second selection input to which a predetermined middle reference voltage is applied, a selection output connected to the control input of said oscillator arrangement, and a selection control input to which the reset output of said oscillator control device is connected, and that said selection device is adapted to connect said first selection input to said selection output if no reset pulse is received at said selection control input, and to connect said second selection input to said selection output if said reset pulse is received.

[0016] This improves the speed of the transfer from one characteristic to another with a reduced frequency jump during the change of the control voltage from the predetermined reference voltage to the predetermined middle reference voltage by the feedback device under control of the activated control signal. This is also useful during a startup phase of the voltage-controlled oscillator. The voltage-controlled oscillator then starts operating with a control voltage in the middle of the supply voltage range. This is called "automatic center frequency calibration" and allows the control voltage to be modified for a same amount up and down from the middle or center frequency.

[0017] In case of use in a mobile telecommunication system as mentioned above, the present voltage-controlled oscillator may further be associated with an external channel controller adapted to control said output signal at said output terminal to have a frequency selected amongst a plurality of predetermined frequencies, said oscillator control device then includes a memory arrangement comprising a plurality of memory cells each storing a control signal, said external channel controller being adapted to control, via a memory control input of said oscillator control device, said memory arrangement to provide, at said control output, one of the control signals stored in said memory cells, and said feedback device then including a frequency divider adapted to perform a division of the frequency of the output signal received at said feedback input by a value provided by said external channel controller via a control terminal of said feedback device, said feedback device being adapted to provide said control voltage as a function of the result of said division.

[0018] Knowing that in a mobile telecommunication system, such as the GSM, the transmission frequency range is divided into a plurality of channels, different frequencies are requested at the output of the voltage-controlled oscillator. Each of these frequencies correspond to a particular channel for which a particular control signal is stored in the memory arrangement and which corresponds to a number or value provided to the frequency divider. In this way, when a particular channel is selected, the associated control signal is immediately provided to the switchable capacitor arrangement for operating the suitable switches. The voltage-controlled oscillator will then immediately switch towards the correct characteristic even when starting from a power-down status.

[0019] In a preferred embodiment, the present invention is further characterized in that said oscillator control device includes a learning algorithm module adapted to update the control signals stored in said memory cells according to a selection signal received from said external channel controller.

[0020] This optimizes the speed for reaching the correct frequency when a particular channel or frequency is selected.

[0021] The present invention also relates to a method to adjust a control voltage of a voltage-controlled oscillator wherein the frequency of an output signal is a function of said control voltage, said method comprising the step of applying said control voltage to a variable capacitor of an oscillator arrangement.

[0022] Such a method is already known in the art and is for instance used in the known voltage-controlled oscillators mentioned above. If the method is so used, the same problems as described above will arise and no suitable solution is known.

[0023] Another object of the present invention is to provide a method adapted to operate a voltage-controlled oscillator with a relatively low power supply, while allowing a large operational frequency range and keeping the production cost low.

[0024] According to the invention, this object is achieved due to the fact that the present method further comprises steps of comparing said control voltage with a predetermined reference voltage, and of controlling the coupling of a capacitor in parallel to said variable capacitor when said control voltage reaches said predetermined reference voltage.

[0025] In this way, when the control voltage reaches the predetermined reference voltage, the fact of coupling, i.e. adding or removing, a capacitor in parallel with the variable capacitor of the oscillator arrangement makes the frequency to jump to another value. As a result, different frequencies may be obtained for a same control voltage and a large frequency range may be achieved with a reduced voltage range for the control voltage.

[0026] Another characterizing embodiment of the present invention is that the method further comprises a step of resetting said control voltage to a predetermined middle reference voltage when said predetermined reference voltage is reached.

[0027] When the control voltage changes, say decreases, until reaching the predetermined reference voltage, the frequency jumps to another value. This new frequency value is lower but corresponds to a control voltage that is not allowed to decrease anymore. By resetting the control voltage to the predetermined middle reference voltage which is preferably a voltage in the middle of the supply voltage range, and thus lower than the actual control voltage, the latter may again decrease, thereby allowing again the frequency to be modified in any direction, i.e. higher or lower.

[0028] It is to be noted that the present method is particularly suited to be applied in the above voltage-controlled oscillator according to the invention.

[0029] Further characterizing embodiments of the present voltage-controlled oscillator, preferably with an automatic center frequency calibration as mentioned above, and of the method to adjust the control voltage thereof are mentioned in the appended claims.

[0030] It is to be noticed that the term 'comprising', used in the claims, should not be interpreted as being restricted to the items listed thereafter. Thus, the scope of the expression 'a device comprising items A and B' should not be limited to devices consisting only of components A and B. It means that with respect to the present invention, the only relevant components of the device are A and B.

[0031] Similarly, it is to be noticed that the term 'coupled', also used in the claims, should not be interpreted as being restricted to direct connections only. Thus, the scope of the expression 'a device A coupled to a device B' should not be limited to devices or systems wherein an output of device A is directly connected to an input of device B. It means that there exists a path between an output of A and an input of B which may be a path including other devices, arrangements and/or means.

[0032] The above and other objects and features of the invention will become more apparent and the invention itself will be best understood by referring to the following description of an embodiment taken in conjunction with the accompanying drawings wherein:

Fig. 1 represents a voltage-controlled oscillator with automatic center frequency calibration according to the invention;

Fig. 2 shows different control voltage versus frequency characteristics of the voltage-controlled oscillator of Fig. 1; and

Fig. 3 represents a variant of the voltage-controlled oscillator of Fig. 1 with a selection device MX to improve the switching speed.

[0033] The voltage-controlled oscillator shown at Fig. 1 includes an oscillator arrangement OA comprising an oscillator OSC having an output terminal VOUT at which a like named output signal is provided. The frequency of the output signal VOUT is determined by a control or tuning voltage VCTRL applied to a control input OIN of the oscillator OSC. To provide the output signal VOUT at a predetermined frequency, the oscillator arrangement OA comprises a resonant circuit formed by the parallel connection of an inductance L and a variable capacitor or "varicap' CV. This resonant circuit is coupled to the oscillator OSC in order to operate therewith. The value of the variable capacitor CV is controlled in an analog way by the control voltage VCTRL that is derived from the frequency of the output signal VOUT by a feedback device FB, also included in the present voltage-controlled oscillator.

[0034] The feedback device FB has an input CIN to which the output terminal VOUT is connected and an output COUT at which the control voltage VCTRL is provided as a function of the frequency of the output signal VOUT as will be explained in more detail later.

[0035] Some operational characteristics CHL, CHM, CHH of control voltage VCTRL versus frequency FOUT of the output voltage VOUT of the voltage-controlled oscillator are represented at Fig. 2. These characteristics correspond to different capacitor values of the resonant circuit of OA. Therein appears that the control voltage VCTRL is allowed to vary within a predetermined voltage range from a low reference voltage VTL up to a high reference voltage VTH. According to the value of the capacitor coupled to the oscillator OSC, the frequency FOUT varies along one of the characteristics CHL, CHM or CHH as will be explained in more detail below.

[0036] In order to increase the frequency range wherein the frequency FOUT is allowed to vary, without increasing the voltage range wherein the control voltage VCTRL is allowed to be, a calibration device CD is add-

ed to the voltage-controlled oscillator. The calibration device CD includes two comparators CPL and CPH as well as an oscillator control device OCD.

[0037] On the one hand, the comparator CPL is a low limit comparator comprising a differential amplifier having an inverting input - at which the control voltage VCTRL is applied and a non-inverting input + at which the low reference voltage VTL is applied. An output of the comparator CPL is connected to a low level input LO of a detection circuit DET forming part of the oscillator control device OCD. On the other hand, the comparator CPH is a high limit comparator also comprising a differential amplifier having a non-inverting input + at which the control voltage VCTRL is applied and an inverting input - at which the high reference voltage VTH is applied. An output of the comparator CPH is connected to a high level input HI of the detection circuit DET of the oscillator control device OCD.

[0038] When the control voltage VCTRL reaches one of the limits of the voltage range, i.e. either the lower limit VTL or the upper limit VTH, a signal is provided at a corresponding level input LO or HI of the detection circuit DET by one of the comparators CPL or CPH respectively. The detection circuit DET then activates a control signal and provides it at a detector control output SC of the oscillator control device OCD.

[0039] This detector control output SC is connected to control inputs of a switchable capacitor arrangement SCA also included in the voltage-controlled oscillator. The switchable capacitor arrangement SCA is provided with one or more switchable capacitor circuits coupled in parallel, each switchable capacitor circuit comprising the series connection of a switch SW1, SW2 and a capacitor XC1, XC2. The switchable capacitor arrangement SCA shown at Fig. 1 comprises two switchable capacitor circuits SW1, XC1 and SW2, XC2 connected in parallel with the resonant circuit of the oscillator arrangement OA. In this way, the switchable capacitor circuits are connected in parallel across the variable capacitor CV.

[0040] To further explain the action of the oscillator control device OCD and of the switchable capacitor arrangement SCA on the operation of the voltage-controlled oscillator, we will consider that a first switchable capacitor circuit, say SW1, XC1, is operational, i.e. with the switch SW1 closed, whilst a second switchable capacitor circuit SW2, XC2 has its switch SW2 open and its capacitor XC2 has thus no effect on the resonant circuit L, CV. This situation will correspond the characteristic CHM at Fig. 2.

[0041] As long as the control voltage VCTRL remains within the limits of VTL and VTH, no control signal is activated by the detection circuit DET of the oscillator control device OCD. The oscillator OSC operates then along the characteristic CHM with, as resonant circuit, the parallel connection of the inductance L, the variable capacitor CV and the capacitor XC1.

[0042] If, for instance, the control voltage VCTRL increases, the frequency FOUT also increases. When the control voltage VCTRL reaches the high reference voltage VTH corresponding to a frequency FHM of the output signal VOUT, the comparator CPH detects that situation and sends a signal to the high level input HI of the detection circuit DET. In response to this signal, a control signal is activated at the control output SC of the oscillator control device OCD in order to open the switch SW1 of the first switchable capacitor circuit. By opening the switch SW1, the first capacitor XC1 becomes disconnected from the actual resonant circuit, of which the capacitive value is thereby decreased since only the variable capacitor CV remains in parallel with the inductance L. As a result, the control voltage versus frequency characteristic of the voltage-controlled oscillator becomes CHH instead of CHM. The frequency is then immediately increased from FHM to FHH because of the jump from the characteristic CHM to the characteristic CHH for a same control voltage equal to VTH.

[0043] If, on the contrary, starting again from the characteristic CHM, the control voltage VCTRL decreases, the frequency FOUT also decreases. When the control voltage VCTRL reaches the low reference voltage VTL, the comparator CPL detects that situation and sends a signal to the low level input LO of the detection circuit DET. In response to this signal, the oscillator control device OCD activates a control signal at its control output SC in order to close the switch SW2 of the second switchable capacitor circuit. By closing the switch SW2, the second capacitor XC2 becomes connected in parallel to the actual resonant circuit, of which the capacitive value is thereby increased to CV + XC1 + XC2. As a result, the control voltage versus frequency characteristic of the voltage-controlled oscillator becomes CHL instead of CHM. The frequency is then immediately decreased from FLM to FLL because of the jump from the characteristic CHM to the characteristic CHL for a same control voltage equal to VTL.

[0044] Owing to the two parallel switchable capacitor circuits of the capacitor arrangement SCA coupled over the resonant circuit L, CV of the oscillator arrangement QA, the frequency range of VOUT is increased up to limits going from the lowest frequency FLL of the characteristic CHL to the highest frequency FHH of the characteristic CHH instead of remaining within the limits of only one of these characteristics, e.g. between FLM and FHM on CHM.

[0045] It is to be noted that after a "digital" jump from one characteristic to another, e.g. from CHM to CHH in case of an increasing control voltage VCTRL, the latter voltage is no longer allowed to increase, but may still decrease, while in case of a decreasing control voltage VCTRL and a digital jump from CHM to CHL, the control voltage VCTRL is no longer allowed to decrease, but may still increase. Furthermore, this digital change of characteristic causes an abrupt jump on the smooth analog frequency progression along a single characteristic, which in some application, such as for instance for

fine-tuning, is unwanted.

[0046] The present voltage-controlled oscillator is therefore preferably provided with an automatic center frequency calibration which, by a digital frequency jump, resets the control voltage VCTRL in the middle of the allowed voltage range thereby also resetting the frequency FOUT in the middle of the new characteristic.

[0047] To this end, the oscillator control device OCD is provided with a reset output RES whereat a like-named reset pulse is provided when a control signal is activated at the control output SC. The reset output RES is connected to a control input CT2 of the feedback device FB. If, for instance, the control voltage VCRTL, moving upwards on the characteristic CHM, has reached the high reference voltage VTH, a reset pulse is sent by the oscillator control device OCD to the feedback device FB via the respective terminals RES and CT2. Upon reception of the reset pulse, the feedback device FB changes the control voltage VCTRL, at its output COUT, from the high reference voltage VTH to a middle reference voltage VTM. This middle reference voltage VTM preferably has an intermediate or average value between the low reference voltage VTL and the high reference voltage VTH. The middle reference voltage VTM is preferably also in the middle of the supply voltage range. Owing to the new control voltage VCTRL being equal to the middle reference voltage VTM on the characteristic CHH, the frequency FOUT of the output signal VOUT has changed from FHM at the upper limit of the characteristic CHM to FMH in the middle of the characteristic CHH, instead of being changed abruptly to FHH. As can be seen at Fig. 2, the frequencies FHM and FMH are chosen to be substantially equal. As a result, the control voltage VCTRL may continue to increase on the characteristic CHH and there is no longer a frequency jump during the increase of VCTRL first on CHM and then on CHH.

[0048] The reset of the control voltage VCTRL towards the middle of the control voltage versus frequency characteristic of the voltage-controlled oscillator is called "automatic center frequency calibration". This reset, bringing the control voltage VCTRL at an intermediate value VTM, further also allows the frequency FOUT to be changed again in both directions, i.e. up or down on the characteristic CHH, starting from the average or middle value FMH.

[0049] In a variant embodiment of the present voltage-controlled oscillator, shown at Fig. 3, the transition speed of the control voltage VCTRL from a limit value such as VTH to the middle value VTM is further improved owing to the addition of a selection device MX. The selection device MX has a first input to which the control voltage VCTRL, from the feedback output COUT, is applied, and has a second input to which the middle reference voltage equal to VTM is applied. An output of the selection device MX is connected to the control input OIN of the oscillator OSC. MX is further provided with control input CT1 to which the reset output RES of the oscillator control device OCD is connected. By default, i.e. without reset pulse received, the first input of MX is connected to the output thereof, applying so the control voltage VCTRL directly to the control input OIN of the oscillator OSC as in the embodiment shown at Fig. 1.

[0050] Owing to this improvement, which also reduces the already small frequency jump from FHM to FMH, either the control voltage VCTRL or the middle reference voltage equal to VTM may be applied to the control input OIN of the oscillator OSC according to the presence or not of a reset pulse RES at the control input CT1 of the selection device MX. When such a reset pulse RES is sent by the oscillator control device OCD, the second input of MX is selected and the middle reference voltage VTM is immediately applied to the control input OIN instead of the control voltage VCTRL. As a result, the frequency FOUT of the output signal VOUT is immediately changed from FHM to FMH. The duration of this relatively fast operation corresponds to the time needed by the feedback device FB to change the control voltage VCTRL at its output COUT from VTH to VTM. This is also useful during a startup phase of the voltage-controlled oscillator. Indeed, owing to the presence of the selection device MX, the voltage-controlled oscillator always starts operating with a control voltage in the middle of the supply voltage range.

[0051] The present voltage-controlled oscillator is also particularly suited for mobile telecommunication applications such as for the Global System for Mobile communications GSM. The GSM system uses 125 channels of 200 kHz each, distributed over the frequency range of 935 MHz to 960 MHz. The use of the channels is controlled by an external channel controller DSP as shown in the Figs. 1 and 3. Each channel corresponds to a particular frequency of the output signal VOUT.

[0052] According to the above, each channel may be associated to a particular characteristic, for instance to characteristics such as CHH, CHM or CHL shown at Fig. 2. To this end, each channel also corresponds to a particular position of the switches in the switchable capacitor arrangement SCA, and these positions are controlled by the control signal at the control output SC of the oscillator control device OCD. The 125 control signals, each corresponding to a distinct channel, are then advantageously stored in 125 distinct memory cells of a memory MLA belonging to the oscillator control device OCD of the calibration device CD. Each channel is further associated to a channel code. This channel code is provided by the channel controller DSP to an input CC1 of OCD in order to select the appropriate memory cell in the memory MLA and to extract therefrom the control signal to be applied at the control output SC. An output signal with the correct frequency is then immediately provided at the output terminal VOUT of the voltage-controlled oscillator.

[0053] The channel code is further also applied to control input CC2 of the feedback device FB. This feed-

back device FB comprises, between the feedback input CIN and the feedback output COUT, the cascade connection of a frequency divider DP, a phase/frequency detector FFD and a loop filter LPF. The frequency divider DP has the input CIN at which it receives the output signal VOUT at a frequency selected by the channel controller DSP. DP further has the control input CC2 at which it received the channel code from the channel controller DSP. As the feedback device FD internally always operates at a same frequency, this internal frequency is obtained in the frequency divider DP by dividing the frequency of the incoming signal at CIN by the channel code at the control input CC2. The resulting signal is then provided to the phase/frequency detector FFD of FD

[0054] The phase/frequency detector FFD has control input FRF at which it receives a reference frequency signal, e.g. from a crystal oscillator Xtal. The phase/frequency detector FFD generates a feedback control signal that is a function of difference, in phase or in frequency, between the frequency of the output signal of the frequency divider DP and the reference frequency received at the control input FRF. This feedback control signal is applied to the loop filter LPF of the feedback device FD that, therewith, provides the control voltage VCTRL at the feedback output COUT.

[0055] Owing to the memory cells storing control signals associated to the different possible output signals to be provided at the output terminal VOUT, the voltage-controlled oscillator will immediately reach a steady state, even when starting from a power-down status.

[0056] The present voltage-controlled oscillator preferably also includes a learning algorithm module associated to the memory MLA of the oscillator control device OCD of the calibration device CD. For each channel or output frequency selected by the channel controller DSP, the learning algorithm module detects the control signal really applied to the control output SC of the oscillator control device OCD. As mentioned above, this control signal is first extracted from a memory cell associated to the channel code received from DSP, but may then be adjusted by the control signal VCTRL provided by the feedback device FD. The purpose of the learning algorithm module is to update the contents of the memory cell with the control signal really applied to the control output SC.

[0057] The learning algorithm module optimizes the speed for reaching the correct frequency, and thus the above steady state, when a particular channel or frequency is selected by the channel controller DSP.

[0058] A final remark is that embodiments of the present invention are described above in terms of functional blocks. From the functional description of these blocks, given above, it will be apparent for a person skilled in the art of designing electronic devices how embodiments of these blocks can be manufactured with well-known electronic components. A detailed architecture of the contents of the functional blocks hence is not given.

[0059] While the principles of the invention have been described above in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention, as defined in the appended claims.

Claims

1. Voltage-controlled oscillator including an oscillator arrangement (OA: OSC, CV, L) with a control input (OIN), an output terminal (VOUT) and a variable capacitor (CV), said oscillator arrangement being adapted to provide, at said output terminal, an output signal having a frequency that is a function of the value of said variable capacitor, said value being controlled by a control voltage (VCTRL) applied to said control input,

   characterized in that said voltage-controlled oscillator further includes a calibration device (CD: OCD, CPL, CPH) and a switchable capacitor arrangement (SCA: SW1, XC1; SW2, XC2),

   said calibration device comprising a comparator arrangement (CPL, CPH) coupled to an oscillator control device (OCD) and
   said switchable capacitor arrangement comprising a plurality of switches (SW1, SW2) coupled to capacitors (XC1, XC2),

   in that said comparator arrangement (CPL, CPH) has a first input to which said control voltage (VCTRL) is applied, at least a second input to which a predetermined reference voltage (VTL, VTH) is applied, and an output connected to a level input (LO, HI) of said oscillator control device (OCD),

   in that said oscillator control device (OCD) has a control output (SC) coupled to switch control inputs of said switches (SW1, SW2), said switches being adapted to connect and to disconnect at least one of said capacitors (XC1, XC2) of said switchable capacitor arrangement in parallel to said variable capacitor (CV),

   and in that, in order to control said switches, said oscillator control device (OCD) is adapted to activate a control signal at said control output (SC) if a signal received at said level input (LO, HI) indicates that said control voltage (VCTRL) has reached said predetermined reference voltage (VTL, VTH).

2. Voltage-controlled oscillator according to claim 1, **characterized in that** said comparator arrangement (CPL, CPH) includes a first comparator (CPL) having a first input (-) to which said control voltage (VCTRL) is applied, a second input (+) to which a

predetermined low reference voltage (VTL) is applied, and an output connected to a low level input (LO) of said oscillator control device (OCD),

in that said comparator arrangement (CPL, CPH) further includes a second comparator (CPH) having a first input (+) to which said control voltage (VCTRL) is applied, a second input (-) to which a predetermined high reference voltage (VTH) is applied, and an output connected to a high level input (HI) of said oscillator control device (OCD),

in that the low level input (LO) and the high level input (HI) form together said level input (LO, HI) of said oscillator control device (OCD),

and in that said oscillator control device (OCD) is adapted to control; via said control output (SC), said switchable capacitor arrangement (SCA: SW1, XC1; SW2, XC2) to connect at least one of said capacitors (XC1, XC2) in parallel to said variable capacitor (CV) if said control signal is activated via said low level input (LO), and to disconnect at least one of said capacitors (XC1, XC2) from said variable capacitor (CV) if said control signal is activated via said high level input (HI).

3. Voltage-controlled oscillator according to claim 1, **characterized in that** said voltage-controlled oscillator further includes a feedback device (FB) having a feedback input (CIN) to which said output terminal (VOUT) is connected and a feedback output (COUT) at which said feedback device is adapted to provide said control voltage (VCTRL),

in that said feedback device (FB) further has a feedback control input (CT2) to which a reset output (RES) of said oscillator control device (OCD) is connected, said oscillator control device being adapted to apply a reset pulse to said reset output when said control signal is activated,

and in that said feedback device (FB) is adapted to provide, at said feedback output (COUT), said control voltage (VCTRL) as a function of the frequency of a signal at said feedback input (CIN) when no reset pulse is received from said oscillator control device (OCD), and to provide said control voltage equal to a predetermined middle reference voltage (VTM) when a reset pulse is received from said oscillator control device.

4. Voltage-controlled oscillator according to the claims 2 and 3, **characterized in that** said predetermined middle reference voltage (VTM) has an intermediate value between said predetermined low reference voltage (VTL) and said predetermined high reference voltage (VTH).

5. Voltage-controlled oscillator according to claim 1, **characterized in that** said voltage-controlled oscillator further includes a selection device (MX) having a first selection input to which said control voltage (VCTRL) is applied, a second selection input to which a predetermined middle reference voltage (VTM) is applied, a selection output connected to the control input (OIN) of said oscillator arrangement (OA: OSC, CV, L), and a selection control input (CT1) to which a reset output (RES) of said oscillator control device (OCD) is connected, said oscillator control device being adapted to apply a reset pulse to said reset output when said control signal is activated,

and in that said selection device (MX) is adapted to connect said first selection input to said selection output if no reset pulse is received at said selection control input (CT1), and to connect said second selection input to said selection output if said reset pulse is received.

6. Voltage-controlled oscillator according to claim 1, **characterized in that** said voltage-controlled oscillator further includes a feedback device (FB) having a feedback input (CIN) to which said output terminal (VOUT) is connected and a feedback output (COUT) at which said feedback device is adapted to provide said control voltage (VCTRL),

in that said voltage-controlled oscillator is associated with an external channel controller (DSP) adapted to control said output signal at said output terminal (VOUT) to have a frequency selected amongst a plurality of predetermined frequencies,

in that said oscillator control device (OCD) includes a memory arrangement (MLA) comprising a plurality of memory cells each storing a control signal, said external channel controller (DSP) being adapted to control, via a memory control input (CC1) of said oscillator control device, said memory arrangement to provide, at said control output (SC), one of the control signals stored in said memory cells,

and in that said feedback device (FB) includes a frequency divider (DP) adapted to perform a division of the frequency of the output signal received at said feedback input (CIN) by a value provided by said external channel controller (DSP) via a control terminal (CC2) of said feedback device (FB), said feedback device being adapted to provide said control voltage (VCTRL) as a function of the result of said division.

7. Voltage-controlled oscillator according to claim 6, **characterized in that** said feedback device (FB) further includes a phase/frequency detector (FFD) and a loop filter (LPF),

in that said phase/frequency detector (FFD) is adapted to provide a feedback control signal as a function of the difference between a frequency resulting from said division performed by said frequency divider (DP) and a reference frequency received at a reference frequency input terminal

(FRF) of said feedback device,

and in that said loop filter (LPF) is adapted to provide said control voltage (VCTRL) as derived from said feedback control signal received from said phase/frequency detector (FFD).

8. Voltage-controlled oscillator according to claim 6, **characterized in that** said oscillator control device (OCD) further includes a learning algorithm module adapted to update the control signals stored in said memory cells according to a selection signal received from said external channel controller (DSP).

9. Method to adjust a control voltage (VCTRL) of a voltage-controlled oscillator wherein the frequency of an output signal (VOUT) is a function of said control voltage, said method comprising the step of controlling the value of a variable capacitor (CV) of an oscillator arrangement (OA: OSC, CV, L) by means of said control voltage (VCTRL),

characterized in that said method further comprises steps of

- comparing said control voltage (VCTRL) with a predetermined reference voltage (VTL, VTH), and
- controlling the coupling of at least one capacitor (XC1, XC2) in parallel to said variable capacitor (CV) when said control voltage (VCTRL) reaches said predetermined reference voltage (VTL, VTH).

10. Method according to claim 9, **characterized in that** said method comprises steps of

- comparing said control voltage (VCTRL) with a predetermined low reference voltage (VTL) and with a predetermined high reference voltage (VTH),
- connecting at least one capacitor (XC1, XC2) in parallel to said variable capacitor (CV) if said control voltage (VCTRL) reaches said predetermined low reference voltage (VTL), and
- disconnecting at least one capacitor (XC1, XC2) from said variable capacitor (CV) if said control voltage (VCTRL) reaches said predetermined high reference voltage (VTH).

11. Method according to claim 9, **characterized in that** said method further comprises a step of resetting said control voltage (VCTRL) to a predetermined middle reference voltage (VTM) when said predetermined reference voltage (VTL, VTH) is reached.

12. Method according to the claims 10 and 11, **characterized in that** said predetermined middle reference voltage (VTM) has an intermediate value between said predetermined low reference voltage (VTL) and said predetermined high reference voltage (VTH).

13. Method according to claim 10, **characterized in that** the frequency of said output signal immediately after the coupling of said capacitor (XC1, XC2) is substantially equal to the frequency of said output signal immediately before the coupling of said capacitor.

14. Method according to claim 9, **characterized in that** said voltage-controlled oscillator is associated with an external channel controller (DSP) controlling said output signal (VOUT) to have a frequency selected amongst a plurality of predetermined frequencies,

and **in that** said method further comprises steps of

- storing (MLA), for each of said predetermined frequencies, a control signal for controlling capacitors (XC1, XC2) to be coupled in parallel with said variable capacitor (CV), and
- controlling the coupling of said capacitors by means of a stored control signal corresponding to the frequency selected by said external channel controller (DSP).

15. Method according to claim 14, **characterized in that** said method further comprises a step of updating a stored control signal when said output signal (VOUT) has the frequency selected by said external channel controller (DSP).

16. Method according to claim 9, **characterized in that** said output signal (VOUT) is applied to a feedback device (FB) which derives said control voltage (VCTRL) from the frequency of said output signal.

17. Method according to the claims 14 and 16, **characterized in that** said method comprises steps of

- deriving said control voltage (VCTRL) from said output signal (VOUT) by dividing the frequency of said output signal by a value provided by said external. channel controller (DSP),
- comparing the frequency resulting from the division with a reference frequency (Xtal), and
- generating said control voltage (VCTRL) as a result of the difference of the comparison.

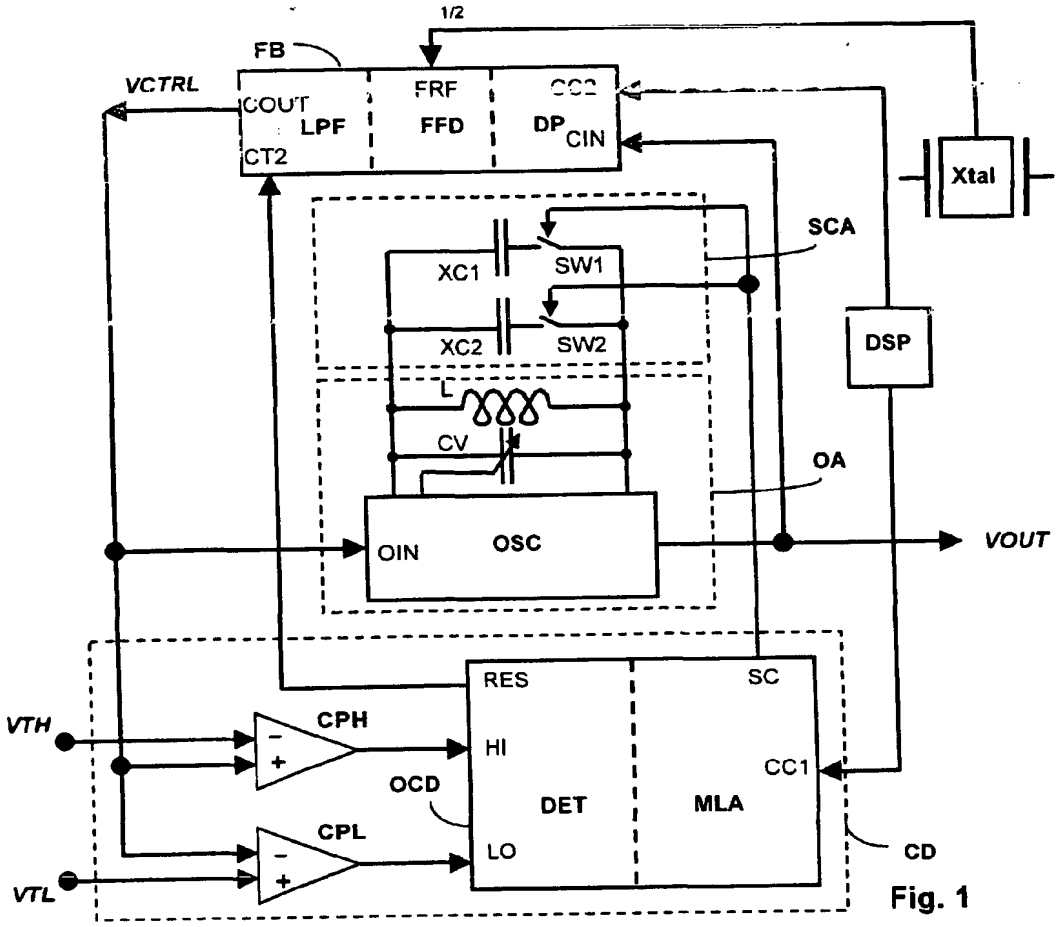

Fig. 1

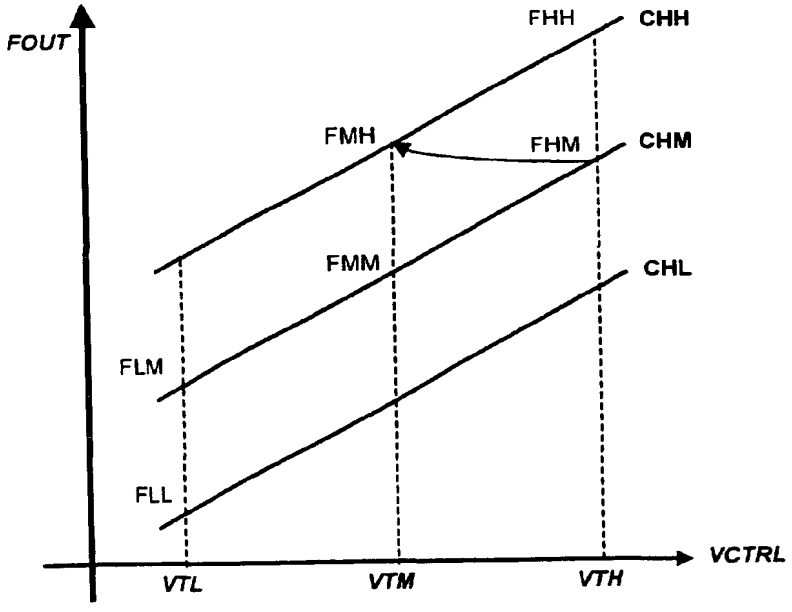

Fig. 2

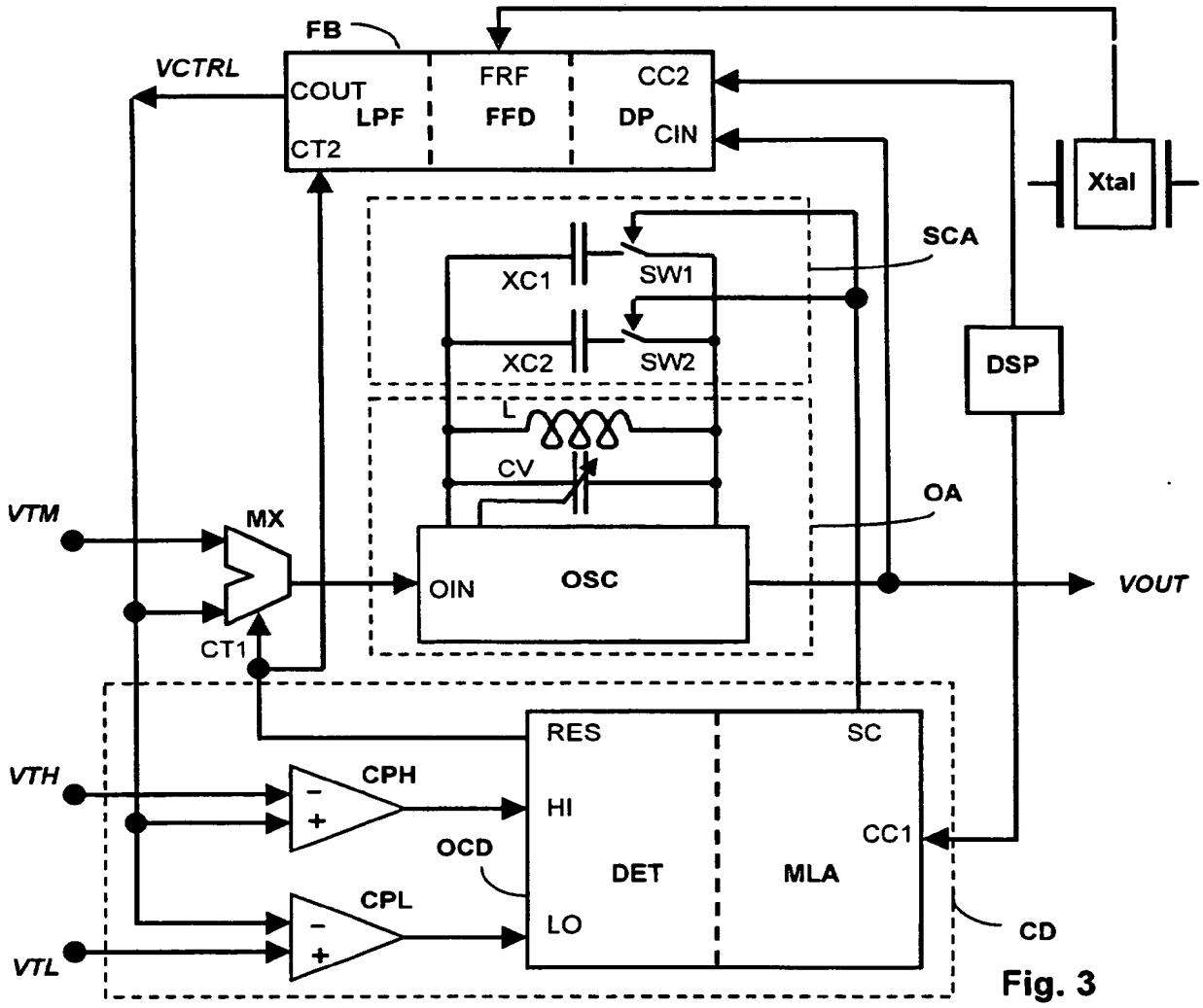

Fig. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 40 2564

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	7 February 2001	Kahn, K-D

CATEGORY OF CITED DOCUMENTS

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